PATENT SPECIFICATION

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1394512

(54) HELICOPTER ROTOR HEAD

(71) We, UNITED AIRCRAFT CORPORATION, a Corporation organized and existing under the laws of the State of Delaware, United States of America, having a place of business at 400 Main Street, East Hartford, Connecticut, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed to be particularly described in and by the following statement:—

This invention relates to helicopter rotor heads and more particularly to such rotor heads which have hubs having redundant load carrying capability so that failure of a portion thereof does not prevent the helicopter rotor from continuing to operate.

In the prior art construction of helicopter rotor heads, the rotor head consisted of monolithic blade retention mechanisms, wherein a failure of the monolithic blade retaining mechanism eliminates the load carrying capability of at least that portion of the rotor. Examples of such monolithic rotor head constructions are shown in U.S. Patent Specifications Nos. 3,428,132; 3,589,835; 3,409,249 and 3,101,785. There is another group of prior art, such as the U.S. Patent Specifications Nos. 1,923,054; 1,797,068; 3,572,969 and 3,551,070 which utilize circular rings in rotor constructions for rotors which are intended to operate at an extremely high rpm and which include loaded webs, spokes and flanges between inner and outer rings, so that the spoke members are loaded by centrifugal force during the normal operation of the rotor, contrary to the teaching of our invention, and so that the circularly shaped outer ring must be made very heavy to retain its shape under load in this high speed application.

These prior art rotors which utilize outer members and spoke members in connection with central hub members are intended for use with very high rotational speed rotors in which a circular outer hoop is necessary to carry the rotor loading. The circular outer hoop of this prior art must be made very rugged so as to be able to carry its own mass in view of its high speed operation in addition to attachment blade loads. The high speed prior art constructions require the outer hoop member to hold the entire unit together, but because the outer hoop would lose its shape due to blade imposed centrifugal forces acting thereon, unless it had very high strength, it is necessary to increase the weight of the circular outer hoop to thereby increase its strength as required. Contrary to the high rotational speed environment of the prior art, the teaching of this application is intended for use with much lower rotational speed environments but with very highly concentrated blade imposed centrifugal loads at discrete points on the rotor. We accordingly avoid using a circular outer ring member because such a circular outer ring member would go out-of-shape under concentrated blade centrifugal loading. We use a plurality of side members connected at high concentrated centrifugal load stations to form a multi-sided truss, thereby keeping the full centrifugal loading in the members forming the periphery of the hub. The importance of our multi-sided truss arrangement is that the loads which are imparted from the blade to the outer truss member extend along the truss members and therefore have less tendency to try to change the shape of those members than is the case with a circular outer hoop. If we had made our outer truss circular in form, a very high concentration of loads at selected stations around the circle would be directed to cause the ring to go out of its circular shape and in so doing would impart loading to our central spokes and our inner hub member.

A primary object of the present invention is to provide a helicopter rotor having a hub with redundant load carrying capabilities consisting of a truss shaped outer support which carries all blade centrifugal loading so to relieve centrifugal loading from the spokes and central hub ring member.

In accordance with the present invention, the hub spoke members cooperate with the

outer support in carrying normal torque, thrust and rotor head moment loading.

This invention permits the complete unloading of the blade central hub of the effects of blade centrifugal loads, thereby permitting this highly stressed central member to more reliably perform its other functions.

In accordance with the present invention, there is provided a helicopter rotor head having a hub member mounted for rotation about an axis of rotation, the hub member comprising an inner support member, an outer support member surrounding said inner support member and a plurality of spoke members extending between and connected to said inner support member and said outer support member, and means connected to said outer support member to support the helicopter blades, characterised in that the outer support member has a plurality of sides connected to form a multi-sided truss, wherein adjacent sides form an apex at their point of intersection and that the spokes are connected to the sides between adjacent apexes and the means to support the helicopter blades are provided at the points of intersection.

Other objects and advantages of the present invention may be seen by referring to the following description read in conjunction with the accompanying drawings.

Figure 1 is a partially broken away view showing in perspective of a helicopter rotor head utilizing our redundant load carrying hub construction.

Figure 2 is a top view of a rotor hub made according to our invention.

Figure 3 is a schematic top view of a rotor hub made according to our invention for the purpose of illustrating the forces acting thereon and being reacted thereby.

Figure 4 is a side view of the Figure 3 schematic rotor head.

Referring to Figure 1 we see helicopter rotor 10 which includes a plurality of blades 12 supported from rotor hub 14 for rotation therewith about axis of rotation 16. Rotor drive shaft 18 is mounted for rotation about axis 16 by conventional bearing supports and is driven in rotation by a conventional engine through a conventional transmission system, and includes spline 20 which engages a corresponding spline on the central ring member 22 of hub 14. A plurality of spoke members 24 project substantially radially out from hub central ring member 22 and support outer support 26 from their outer ends. Each blade 12 is connected to blade retaining yoke 28, which cooperates with spokes 24 and outer support 26 to define interlocked looped members which support spherical elastomeric bearing 30 therebetween. Bearing 30, with the cooperation of centering bearing 32, serves to support blade 12 from hub 14 for universal motion about the intersection of blade pitch change axis 34, blade lead-lag axis 36 and blade flapping axis 38.

A conventional lead-lag damper (not shown) is connected to yoke 28 through bearing 40 in known fashion. Conventional swashplate mechanism 42 is mounted on drive shaft 18 and connected to blade 12 through a conventional blade pitch horn (not shown), operating in conventional fashion to cause blades 12 to vary in pitch both cyclically and collectively.

It should be noted by viewing Figure 1 that spokes 24 are formed from upper flange member 44 and lower flange member 46, which are connected to and project outwardly from central hub member 22 so that hub 14 is actually a one piece, integral unit.

Hub 14 is shown in greater particularity in Figure 2. Hub central member 22 is shown to have axially extending splines on its inner diameter and, together with the remainder of the hub 14, is concentric about axis of rotation 16. Spokes 24 project substantially radially from inner member 22 and attach to outer support member 26 so that hub 14 is an integral unit. Outer support member 26 is actually fabricated as a truss member comprising a plurality of sides 26*a*, 26*b* and 26*c*, for example, which are joined at apexes, such as 48*a*, 48*b* and 48*c*. Apertures such as 50*a*, 50*b* and 50*c* in member 26 at apexes 48*a*, 48*b*, 48*c*, etc. receive and support blade centering bearing 32 (see Figure 1). By viewing Figures 1 and 2, it will accordingly be seen that hub central member 22 is actually a sleeve member of circular cross section mounted concentrically about axis 16, that spokes 24 are actually formed in both the upper flange member 44 and the lower flange member 46, and that outer support 26 extends between these flange members 44 and 46.

It is important to note that outer support member 26 of hub 14 consists of a series of members joined to form a symmetric, multi-sided truss member, and while six such sides are shown in Figure 2, it should be borne in mind that any number of sides could so cooperate, with as few as three sides if a three bladed rotor is to be used. It will further be noted by viewing Figure 2 that the blades 12 (see Figure 1) are to be attached to the outer support member 26 at the apexes or points of intersection 48 of the members 26*a*, 26*b*, 26*c*, etc. and that spokes 24 are connected to the outer support member 26 at stations remote from said apexes 48, and preferably substantially midway between adjacent apexes 48. This construction is very important for the reasons to be described hereinafter.

For an explanation of the types of loads which a rotor hub must withstand and for an explanation of how the hub construction taught herein reacts these loads during normal

rotor operation and following hub failure in redundant operation, consideration will now be given to Figures 3 and 4 of the drawings. First, let us consider the four types of loads which hub 14 must react between blades 12 and drive shaft 18. The first force, centrifugal force, is the force imparted to the hub by the blade due to centrifugal force attempting to throw the blade outwardly from the hub during rotor rotation. These loads are substantially radial in direction and, because blades 12 are positioned at stations 48, the loads of centrifugal force, designated by the arrows C.F. in Figure 3, act at points 48*a*, 48*b*, etc. in a radial direction. The second load is called torque and is brought about by the inertia of each blade in attempting to lag behind the rotor during rotor start-up or attempting to lead the rotor during rotor braking operation, and at other times during rotor operation. This force is indicated by the arrow marked "torque" in Figure 3. The third load is called thrust and is a vertical loading imposed upon the rotor hub by the lifting force of the blade and is indicated by arrows so marked in Figure 4. The fourth load is called the rotor head moment and is caused by the difference in lifting potential between the faster traveling advancing blades and the slower traveling retreating blades and is indicated by the arrow marked "head moment" in Figure 4.

We will now consider how these four loads act upon motor hub 14 and are reacted thereby in normal operation and following hub fracture wherein the redundant load carrying operation takes place. It is a very important teaching of our invention that outer support 26 takes all of the centrifugal load of hub 14 so as to free spokes 24 and inner hub member 22 thereof. Inner hub 22 has many other steady-state forces and loads which it must carry and its size may be reduced and its structural integrity increased if outer support 26 can react all blade centrifugal loading for hub 14. Let us consider the effect of centrifugal force C.F. at intersection or apex 48*d* between straight sides 26*c* and 26*d* of outer support member 26. The centrifugal force load vector C_F at intersection 48*d* loads straight legs 26*c* and 26*d* equally and in opposite directions as shown by arrows 50 and 52, which illustrate that one half of the blade centrifugal force C_F at station 48*d* is taken by leg 26*c* and half thereof is taken by leg 26*d*. Similar loads 54 and 55 are imposed at intersection 48*c* by centrifugal force C.F. of the blade there, and it will be noted that forces 50 and 55 are in opposite directions on straight leg 26*c*, thereby placing that leg in tension. Since similar forces act upon each succeeding leg 26*a*—26*f*, the entire outer support or truss member 26 is loaded in hoop tension so as to carry all of the blade centrifugal loading therein, without having to impart any thereof through spokes 24*a*—24*f* to hub central member 22. Outer member 26 reaction of centrifugal load forces 50—55 are indicated by arrows 56—59. It is an important teaching of our invention that outer member 26 be multi-sided so as to form a truss so that these blade centrifugal loads and reactions shown by arrows in Figure 3 are directed in straight-line action along the sides of the truss so that truss member 26 retains its shape while carrying these discretely positioned and heavy blade centrifugal loads. If member 26 were circular in form, the centrifugal blade loads would react in bending in directions upon the circular outer member 26 that they would tend to pull the circular member 26 out-of-round and hence, member 26 would have to be strengthened substantially, as in the prior art, to withstand centrifugal loading. It will further be seen that during normal rotor operation, hub 14 reacts blade centrifugal loading so that each side member 26*a*—26*f* carries and reacts one half of the centrifugal load imposed by the blade at each of its opposite ends, thereby placing the sides of the truss in tension and the entire truss member 26 in hoop tension.

Now let us consider the redundant operation of hub 14 in reacting centrifugal loads when a fracture occurs in outer member 26. Let us presume in viewing Figure 3 that a fracture occurs in outer member 26 at station 60. Such a fracture at station 60 in outer straight leg 26*d* would set up a counterclockwise cantilevered load in leg 26*c* about intersection 48*c* and would therefore impose centrifugal loading upon spoke 24*d* and central member 22. Similarly, a clockwise centilevered load would be imposed upon straight leg 26*d* about intersection 48*e* and thereby impose centrifugal loading upon spoke 24*e* and hub central member 22. It is therefore seen that if a fracture occurs in one of the sides of outer member 26, the centrifugal loading is imparted through the adjacent spokes thereof to central member 22. In practice, a fracture in outer member 26 at station 60 would not only impart centrifugal loading to spokes 24*d* and 24*e* but would less significantly impart centrifugal loading to the remaining spokes as well.

From a redundancy standpoint, since all centrifugal loading is taken by outer member 26, a fracture in any of the spokes 24*a*—24*f* or central member 22 is tolerable with respect to the reacting of blade centrifugal loads.

Now considering how rotor reacts torque loading, it should be noted that the reacting of torque loading is the main purpose of spokes 24*a*—24*f*. For example, during rotor start-up operation, the drive engine is causing central shaft 18 to rotate and, shaft 18 is, in turn, causing inner hub member 22 to rotate therewith. This torque loading is imparted

through spokes 24a—24f to the outer truss member 26 so as to carry the blades 12 along therewith. Accordingly, spokes 24a through 24f share torque loading substantially equall during normal rotor operation. In the event of fracture of one or more of the spokes, the remaining spokes cooperate to carry torque loading substantially equally. A fracture in the outer truss member 26 would be immaterial from the torque loading standpoint, since torque would be applied from the radial spokes to the outer truss member 26 on both sides of the fracture. Specifically, at fracture 60 radial spoke 24d would carry torque loading to intersection 48d.

Now, considering how hub 14 reacts thrust loading, let us consider Figure 4. As previously described, thrust loading is a vertical loading imposed upon hub 14 due to blade lift forces as shown by the thrust arrows in Figure 4. During normal rotor operation, such thrust loading would be reacted in the rotor hub 14 by placing the upper surface or flange 44 thereof in compression, as shown by arrows 62 and 64, and placing the lower surface or flange 46 thereof in tension as shown by arrows 66 and 68. Now, let us consider that a fracture occurs in outer truss member 26 at station 60 in side 26d. The blade at intersection 48a would be imposing an upward force at station 48a, and such force would be imposing a cantilevered moment on arm 26c, and also on spoke 24d so as to place the upper surfaces thereof in compression and the lower surfaces thereof in tension. At the same time, the blade at station 48e is lifting upwardly and would impose a cantilevered moment on straight side 26a and spoke 24e so as to place the upper surfaces in compression and the lower surfaces in tension. The remainder of the thrust load from the blade at station 48e would be imparted in cantilevered fashion to straight side 26e and spoke 24f so as to place their upper surfaces in compression and lower surfaces in tension.

Now let us consider the head moment force, bearing in mind that this force is caused by the different lifting capability of the blades and is actually an overturning moment between the blades and the central hub caused by this different blade lifting performance. We must consider this head moment as an attempt for the entire rotor to bend drive shaft 18 through the central hub ring 22. Accordingly, spokes 24a—24f are the structures which are going to react this overturning moment by having their upper surfaces placed in compression and their lower surfaces placed in tension to absorb or react this head moment loading. To demonstrate the redundant capability of our rotor construction 14 shown in Figure 3, let us assume that during operation, spoke 24e fractures. Under these circumstances, the blade at station 48e will impose a lifting moment so to place the upper surface of straight side 26e and spoke 24f in compression and their lower surfaces in tension. The blade at station 48e will also apply similar loading to straight sides 26a and 26c and will apply a twisting loading on spoke 24d. In this way, our rotor hub 14 will redundantly react head moment loading when spoke 24e fractures.

It is an important teaching of our invention that spokes 24a—24f are substantially perpendicular to the respective sides 26a—26f which they join, the junctions being remote from side member intersections 48a—48f so as to be free of the influence of blade centrifugal force. Preferably, the spokes are positioned substantially midway between adjacent intersection stations 48a—48f and this provides the added advantage of providing substantial space envelopes 25a—25f to receive the blade support structures 26—40 shown in Figure 1. If spokes 24a—24f were in substantial alignment with the blades 12 at points of intersection 48a—48f, or tangentially parallel to truss member 26, the blade centrifugal loading would be at least partially imparted thereto and this would be completely contradictory to the purpose and teaching of this invention, in that our objective is to have all centrifugal loads taken by the outer truss member 26 only and the spokes 24 to be fully relieved of centrifugal loading. The major advantage to be gained by relieving the spokes 24 of centrifugal loading is that, in turn, the hub inner ring member 22 is also relieved of centrifugal loading and this is desirable practice since inner ring 22 is a heavily stressed and loaded structure which has many other loads to carry and whose reliability will be increased if relieved of the centrifugal loading. An alternative construction would have been to strengthen the inner ring 22 and the radial spokes 24 sufficiently so as to be able to carry all of the loads imposed thereon, including the centrifugal loading, and thereby eliminate outer truss member 26, however, this alternative structure would not produce a redundant load carrying structure. It will therefore be seen that the utilization of the outer truss member 26 not only gives redundancy to our hub, but relieves the inner hub member 22 of centrifugal loading so that it can better carry the loads imposed upon it by its other required functions, including carrying torque and thrust loads.

While rotor 10 has been described as a conventional main helicopter rotor, our invention is equally applicable to a helicopter tail rotor, and any helicopter rotor without respect to its attitude of orientation.

WHAT WE CLAIM IS:—

1. A helicopter rotor head having a hub member mounted for rotation about an axis

of rotation, the hub member comprising an inner support member, an outer support member surrounding said inner support member and a plurality of spoke members extending between and connected to said inner support member and said outer support member, and means connected to said outer support member to support the helicopter blades, characterized in that the outer support member has a plurality of sides connected to form a multi-sided truss, wherein adjacent sides form an apex at their point of intersection and that the spokes are connected to the sides between adjacent apexes and the means to support the helicopter blades are provided at the points of intersection.

2. A rotor head according to claim 1, characterized in that said spokes connect to said outer support member at a station substantially midway between adjacent apex intersections.

3. A rotor head according to claim 2, characterized in that said spokes are oriented so as to extend substantially perpendicularly to the sides to which they are connected respectively.

4. A rotor head according to claim 1, characterized in that said central member, said spokes and said outer member are connected to form an integral unit.

5. A rotor head according to claim 1, characterized in that said outer support member is in the shape of a truss having at least three sides.

6. A rotor head according to claim 1, characterized in that said central support member is a ring member of selected height and wherein said spoke members are part of upper and lower flange members connected to and projecting from the central members, and wherein said outer support member includes upper and lower flange members connected and supported from the upper and lower flanges of said spoke members respectively.

7. A rotor head according to claim 1, characterized in that said spoke members constitute the sole support between said central support member and said outer support member.

8. A rotor head substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

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1394512 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG. 1

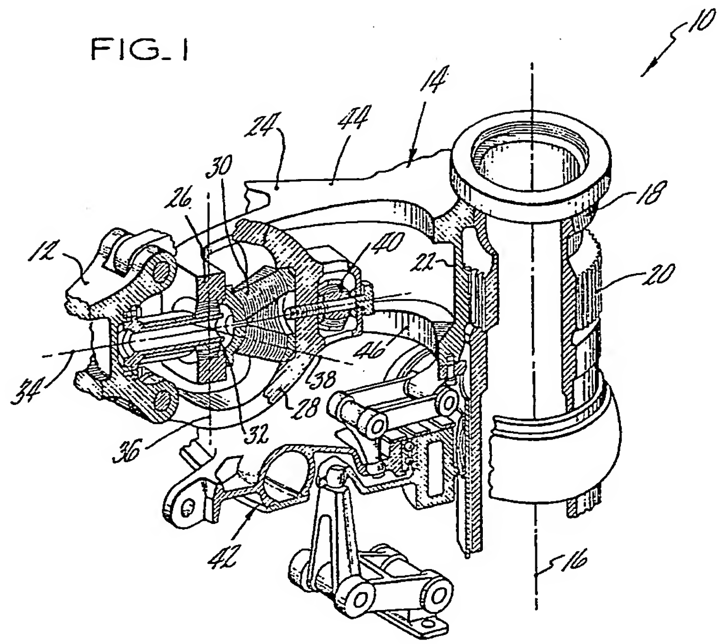

FIG. 2

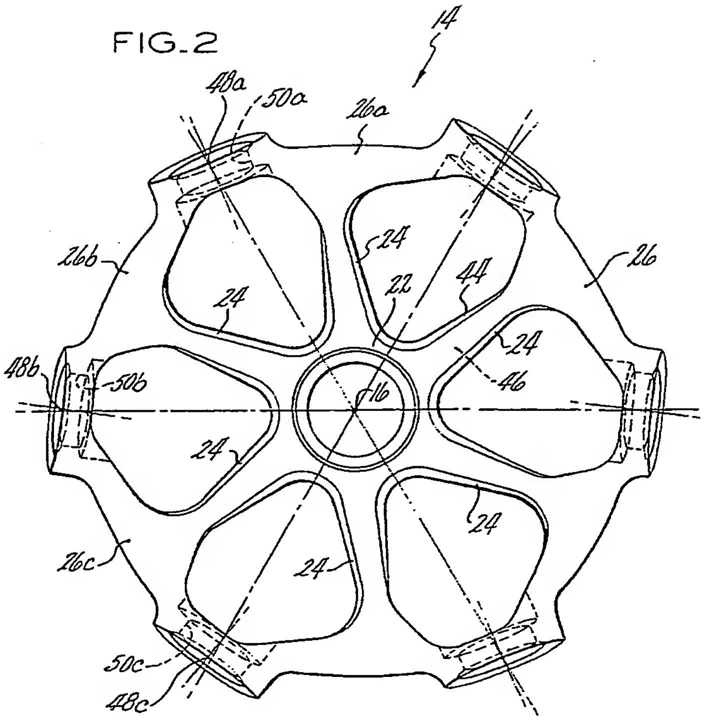

FIG. 3

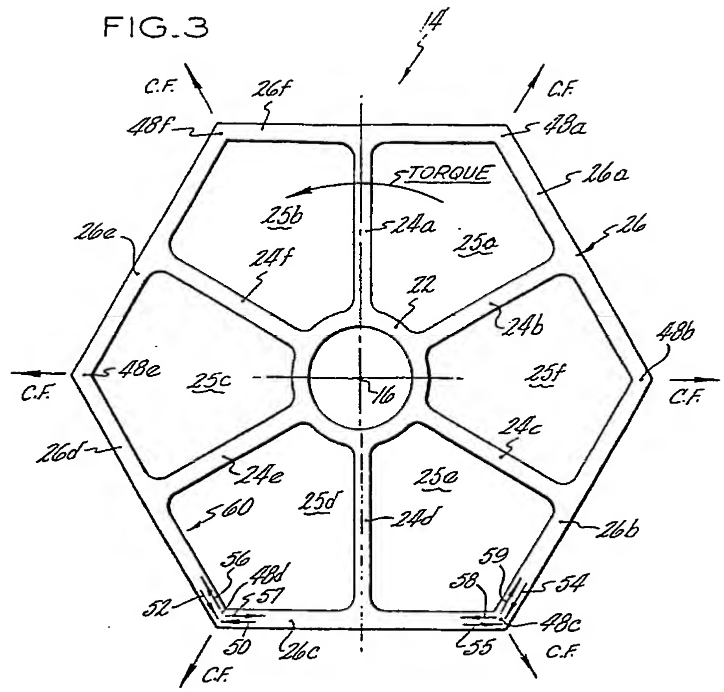
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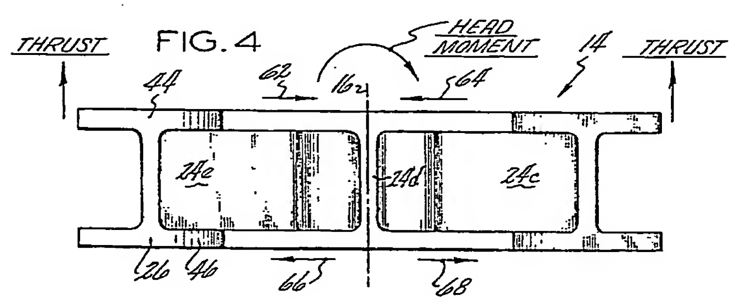
FIG. 4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